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The Far-Ultraviolet Radiation from Elliptical Galaxies

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Since the discovery of the Ultraviolet Upturn Phenomenon ("UVX") in early-type galaxies it has been clear that the stellar populations of such systems contain an unexpected hot component. Recent work has provided strong circumstantial evidence that the stars radiating at short wavelengths ($\lambda < 2000$ Å) is in fact due to hot horizontal branch, post-HB stars and post-AGB stars. We summarize the arguments in favour of this hypothesis. We then derive an estimate for the fraction of all HB stars that must be contributing to the UV upturn phenomenon in the strongest UVX galaxy, NGC 1399, and derive a hot star fraction $f_H \sim 0.16$. The implication is that UVX arises from a minority fraction of the dominant stellar population. We conclude that the mechanism that produces the UVX is not one that can be explained naturally by the presence of an extremely metal-rich or metal-poor population.

1. Introduction

The Ultraviolet Upturn Phenomenon was first found by the OAO-2 spacecraft in the late sixties (Code 1969). It consists of a 'UV rising branch' at wavelengths shorter than $\lambda < 2500$ Å, which varies in amplitude amongst the galaxies observed. The amplitude of the UVX phenomenon varies by a factor of about 10 from NGC 1399 [$(15 - V) = 2.05$] to M32 [$(15 - V) = 4.50$] with very similar slopes in the IUE spectral range ($\lambda < 1200$ Å).The question was investigated in further detail by Burstein *et al.* (1988, hereafter B3FL) who presented a sample of galaxies observed by the International Ultraviolet Explorer (IUE). They determined the UV/Optical color $m_\lambda(1550) - V$ [hereafter $(15 - V)$] from ground-based photometry. They plotted these colors against the absorption line index Mg_2, a reliable metallicity indicator for the Galactic globular cluster system (Burstein *et al.* 1984; Brodie & Huchra 1990), and the central velocity dispersion σ_0. For the galaxies that are quiescent, i.e. which contain no evidence of recent star formation and nuclear activity there is a non-linear correlation between Mg_2 and the UVX amplitude (see also Faber 1983). The UVX was also found to correlate, albeit not as tightly, with σ_0, which is an indicator of luminosity through the Faber-Jackson relation. Thus either the amplitude increase is directly related to the metallicity (or at least magnesium abundance) of the galaxies, or there is a tendency for bright galaxies to have strong UV upturns. Enhancements in α-capture elements such as Mg have been found to be a feature of the spectra of bright ellipticals (Worthey, Faber, & Gonzalez 1992) and imply something about the early enrichment history of massive systems.

This contribution is organized as follows: in the next section we discuss the recent observational evidence pertaining to the UVX. Section 3 summarizes the problems associated with modelling the Horizontal Branch. In §4 we give an overview of evolutionary population synthesis, and use it to derive estimates of the fraction of hot stars present as a function of the UV upturn strength. §5 discusses these estimates in the light of population models for the UVX.

2. The 'Old Population' Model

2.1. *UV sources in Old Populations*

The potential sources of UV radiation in old stellar populations have been reviewed in detail by Greggio & Renzini (1990), to which the reader is referred for a full discussion. Briefly, the sources that are likely to produce the largest contribution to the UV output from a galaxy are evolved stars powered by stable nuclear reactions. The production of a hot star on the HB requires that much or all of the hydrogen rich envelope has been stripped from the star prior to arrival on the HB. The sources are (see Dorman, Rood, & O'Connell 1993, hereafter DRO93 and references therein):

- Post-Asymptotic Giant Branch (P-AGB) stars, which are bright ($L/L_{\odot} \sim 1,000 - 10,000$) but short-lived ($t \lesssim 25,000\,\mathrm{yr}$) . These are likely the most common 'exit channel' for metal-rich stars dying as white dwarfs after going through thermal pulses on the AGB.
- Post-Early Asymptotic Giant Branch stars, which miss the thermally- pulsing stage of AGB evolution, and cross the HR diagram at $L/L_{\odot} \sim 1,000$ in $\sim 10^6\,\mathrm{yr}$.
- Hot Post-HB stars, termed AGB-Manqué stars, which are intermediate in brightness ($L/L_{\odot} \sim 100 - 500$) and lifetime ($t \sim 2 - 4 \times 10^7\,\mathrm{yr}$).
- Hot Horizontal Branch (HB) stars, which are fainter ($L/L_{\odot} \sim 10-50$) but long-lived ($t \sim 10^8\,\mathrm{yr}$). For convenience, these are grouped as either "Intermediate Blue HB stars" (IBHB) if their envelopes are large enough to allow ascent up the AGB, and "Extreme HB stars" (EHB) if not.

All of these sources have their observational counterparts in the Galactic field or in globular clusters (see DOR95 and Dorman 1997a,b for summaries). P-AGB stars are present as UV-bright stars or the nuclei of planetary nebulæ. Their total UV lifetime radiation (and contribution to the integrated spectrum) in this phase decreases strongly with increasing luminosity, since both the total fuel available to them decreases and its rate of consumption increases. It is well-known that hot HB stars are produced in large numbers in metal-poor globular clusters. The Galactic field hot subdwarfs (designated sdB, sdO and variants; see Greenstein & Sargent 1974; Saffer *et al.* 1994) dominate the UV excess sources in surveys of our Galaxy (Green, Schmidt, & Liebert 1986 and others). They are kinematically related to the old disk (Saffer & Liebert 1995) which is predominantly metal-rich compared to the halo clusters. The sdB stars occupy the same HR diagram location as the EHB stars. The AGB-Manqué stars, progeny of the EHB population, are similarly associated with the sdO population.

The elliptical galaxies are dominated by metal-rich populations (probably of solar metallicity or above). Until recently, the only evidence for hot HB stars in a metal-rich environment was in the Galactic field. There were no unambiguously metal-rich populations that contained them i.e. in the coeval, homogeneous Galactic clusters. However, Liebert, Saffer, & Green (1994) found a number of sdB stars in the super-metal-rich ([Fe/H] ~ 0.2; Tripicco *et al.* 1995) Galactic old open cluster NGC 6791. Very recently, Rich *et al.* (in preparation; see also Piotto *et al.*, these proceedings) found well-populated blue tails in the metal-rich clusters NGC 6388 and NGC 6441. While the process that gives rise to these hot stars is unknown (and may not be relevant to galaxies), taken with the field sdB/sdO objects, these clusters provide an "existence theorem" for hot helium burning stars in metal-rich populations.

2.2. *The Nature of the UVX Phenomenon*

The most obvious originating stellar population for the UVX is a small population of young, massive stars, and several studies based on this hypothesis appeared. However, later work with with the resolving power of HST (King *et al.* 1993) appears to rule out

this hypothesis for M31. King *et al.* found an underlying smooth flux distribution increasing toward the nucleus with none of the discreteness found for OB associations, which in any case had no concentration toward the centre. Also, some of the flux ($\sim 20\%$) emanated from resolved P-AGB stars.

Hills (1971) first suggested that post-asymptotic giant branch stars might be the source of the upturn found in the bulge of M31 [$(15-V) = 3.5$]. Brocato *et al.* (1990) and Greggio & Renzini (1990) both showed that the maximum possible UV flux given by the numbers of P-AGB stars expected from standard stellar population models was insufficient to account for the amplitude of the strongest UV upturns. Ferguson & Davidsen (1993) contrasted Hopkins Ultraviolet Telescope (HUT) spectra of the strongest UVX system, NGC1399 [$(15-V) = 2.05$] and that of M31 and concluded that (a) in the IUE spectral range ($\lambda > 1250$ Å) much of the flux emanated from sources with characteristic temperature of $\sim 25,000$ K and (b) the spectral energy distributions (SEDs) did not match at the short end of the spectrum ($\lambda < 1200$ Å), with the flux from M31 being hotter. This is consistent with the notion that a larger proportion of the UV flux from M31 comes from the P-AGB stars, which have a much higher time-averaged effective temperature. These conclusions are corroborated by the later studies of Brown, Ferguson, & Davidsen (1995) and Brown *et al.* (1997), who found similar characteristic temperatures in six other elliptical/S0 galaxies. Their spectral fits to the Astro-2 HUT data suggest, under a large range in assumptions about the P-AGB stars in the galaxies, that at least some EHB stars are apparently present in all systems. Thus the model that appears to be consistent with the observations is of an old population where the UV flux emanates partly from the P-AGB stars and partly from EHB stars.

3. The Horizontal Branch Mass Dispersion

The HB stars are the hottest potential source of UV radiation in an old ($t \gtrsim 2$ Gyr) stellar population and have moderate intrinsic luminosities with appreciable stellar lifetimes. However, it is well-known that modelling HB populations in Galactic globular clusters is subject to a major difficulty, *viz.* that of the mass dispersion. Iben & Rood (1970) first realized that the observations implied a scatter in HB properties, and Rood (1973) explicitly showed using 'synthetic' HB sequences that a dispersion in HB envelope masses could reproduce the observations. However this quantified rather than explained the dispersion in mass, likely due to mass loss on the red-giant branch, by mechanisms still poorly understood to this day. The hottest HB stars are produced by extreme mass loss (Ciardullo & Demarque 1977; Caloi 1989; Castellani & Tornambè 1991; DRO93). Also, as clusters age, the models imply that the RGB mass decreases so that less mass needs to be stripped to produce hot HB stars in older populations. Synthetic HB models thus show a passive drift of the HB sequences blueward as a cluster ages, which mimics the effect of higher mass loss.

Iben & Rood (1970) also noted the variations of HB stellar properties with envelope mass, metallicity, helium abundance Y (see also Sweigart & Gross 1976), the CNO element fraction, as well as the core mass, although the variations in the latter are constrained by energy arguments. As a result, cluster observations are subject to many possible interpretations (aside from observational problems such as determinations of reddening, calibration of blue stars, etc etc).

In Galactic clusters it is possible to identify the resolved hot stars as members of the HB. In studying the stellar populations of galaxies, however, we must start by asking a more basic question, i.e. 'which stars are actually responsible for the UV radiation?'

The following step is to explain the observed UVX correlation in terms of the galaxy properties, but the interpretation is still not straightforward (see §5).

In a detailed study of the possible explanations for the UVX, Greggio & Renzini (1990) suggested that an increase in the mass loss with metallicity would produce blue HB stars. The assumptions involved both an increase in mass loss with metallicity (almost universally acknowledged to happen, although without quantitative theoretical backing), and an extrapolation of the helium enhancement vs. metallicity relations derived at low metallicity to the super-solar metallicity regime. By using simple analytical fits to the behavior of the HB stars and the HB morphology with increasing metallicity, they showed how the UVX-metallicity correlation might be produced naturally, by properties of stellar evolution rather than of the galaxy environment. Environmental effects such as galaxy size, density or previous history are necessarily more difficult to quantify, but may be relevant to the problem: we regard these as 'stellar populations' inputs to the problem as distinct from those of stellar evolution (*cf.* Dorman 1996).

4. Modelling of Ultraviolet Bright Old Populations

The unresolved stellar populations of galaxies are studied using the methods of evolutionary population synthesis (*cf.* Tinsley 1980; Renzini & Buzzoni 1986; see also Bruzual & Charlot 1993). Evolutionary population synthesis attempts to model the integrated spectrum of a stellar population by summing the contributions at each individual wavelength arising from the population components assumed to be present. We sketch here the derivation of values for UV/Optical colours such as $(15 - V)$.

4.1. *Population Synthesis in a Nutshell*

Since the evolutionary connection between the early and late stages of evolution is broken by the indeterminate nature of the RGB mass loss process it is convenient to break the problem into pre-He flash $\mathcal{L}_\lambda^{\rm E}$ and post-He flash $\mathcal{L}_\lambda^{\rm L}$ stages. We consider the integrated light from each component with fixed composition $\mathbf{X} = (Y, Z_\alpha, Z_{\rm CNO}, Z_{\rm Fe-peak})$ etc. For populations old enough to produce RGB sequences, the equation for the luminosity in any given bandpass designated by λ is (see DOR95 for more details)

$$\begin{aligned}\mathcal{L}_\lambda(\mathbf{X}) &= \mathcal{L}_\lambda^{\rm E} + \mathcal{L}_\lambda^{\rm L}\\ &= \int d\tau \int dm' L_\lambda(m';\mathbf{X})\Psi(m',\mathbf{X},\tau)dm'\\ &\quad+\dot{n}_0(t)\mathcal{L}_{\rm V}^{\rm E}\Delta V_0 \int_0^{M_{\rm RGB}-M_c} P(m';\mathbf{X})E_\lambda(m';\mathbf{X})\,dm'. \end{aligned}\tag{4.1}$$

where

$$E_\lambda(M,\mathbf{X}) = \int_{ZAHB}^{WD} L_\lambda(M,\mathbf{X})dt. \tag{4.2}$$

The first term here is the contribution of the early (pre-RGB) evolutionary phases, and is shown here schematically as an integral over time and mass. The time integral is over the interval where the star formation rate is significant, and the mass integral goes from the lower end of the main sequence to the RGB tip. The luminosity L_λ of a star at λ is modelled using the relation

$$L_\lambda(M,t,\mathbf{X}) = \alpha_\lambda(g,T_{\rm eff},\mathbf{X})L_{\rm bol}(M,t,\mathbf{X}) \tag{4.3}$$

where α_λ is the 'bolometric correction,' i.e. the proportion of the total flux radiated in the band designated by λ. This is quite general: λ can be a narrow pass (a few angstroms) for the construction of synthetic spectral energy distributions, or a broadband color such as a Johnson filter. The values of α_λ are supplied using either an empirical flux library (more realistic, but never complete and hard to calibrate over long wavelength baselines), or synthetic stellar fluxes (e.g. Kurucz 1991). The latter have the great advantage of completeness, but their accuracy particularly at short wavelengths is difficult to test at different metallicities. Their use also presupposes the accuracy of temperature/SED relations derived from the library of model stellar fluxes.

As for the late stages, the terms in the equation are the integrated lifetime energy output from the ZAHB to the end of the white dwarf stage. This term is simplified by the fact that the core mass changes almost negligibly with cluster age (for $t \gtrsim 5\,\mathrm{Gyr}$), so that the properties of the ZAHB are invariant with time. The unknown mass distribution of the ZAHB stars due to variable mass loss on the RGB is denoted by $P(m, t, \mathbf{X})$. The lifetime energy flux [equation (4.2)] is multiplied by the 'specific evolutionary flux,' denoted as $\dot{n}_0(t, \mathbf{X})$, which is the input rate *per unit magnitude of pre-HB population* arriving on the HB. $\dot{n}_0$ was approximated by Renzini & Buzzoni (1986) and DOR95 as the number of stars leaving the main sequence, but it is also possible to derive this number from the RGB evolutionary tracks or empirically (O'Connell 1980). $\mathcal{L}_{\mathrm{V}}^{\mathrm{E}}$ is the V band luminosity from the pre-He flash stages, and ΔV_0 is a constant, the width of the V filter ($= 872$Å).

Potentially, both the IMF Ψ and the HB mass distribution function P are affected by factors beyond stellar evolution in single stars: this is the 'stellar populations' component to the problem. The effects of the initial conditions (such as rotation, composition inhomogeneities, dynamics and environment) are not understood. In the case of the IMF, we can show that for low mass stars, the power law functions fit to cluster and field populations do not much affect the output model spectra. The same is not true for the HB mass distribution where small changes can produce large effects in the ultraviolet output. It is thus somewhat misleading to write $P(M)$ as an implicitly single-valued function of age and composition, as would be correct if only stellar evolution had an impact on the problem. P can however be constrained empirically and the model tested for consistency against its other observational predictions.

4.2. *The Energy Function $E_\lambda\,(M)$*

Figure 1 shows the lifetime energy radiated by HB stars as a function of envelope mass at 1500 Å and in the V band. Here we have assumed that red HB stars evolve through the P-AGB channel that is the most favourable (i.e., lowest mass) for UV production. The models used are from DRO93 with the P-AGB flux from the Schönberner (1983) $M_{bol} = -3.2$ ($M = 0.546\,M_\odot$) model. The thin lines show the energy radiated up to the core He exhaustion point. The regimes of M_{env} labelled show (a) red HB stars (with far-UV radiation only in the P-AGB stage); (b) the IBHB stars, which reach the AGB after core helium exhaustion: these are the stars that populate the part of the HB usually thought of as the 'blue HB' in globular clusters such as M3; and (c) the EHB stars whose total post-HB energy radiated is similar to that emitted before core He exhaustion. The pre–core-He exhaustion energy radiated by the EHB stars is seen to be approximately constant with envelope mass and similar to the maximum post-HB output. Models for other metallicities (DRO93, DOR95) show that the total far-UV radiation from all EHB stars from (Y, [Fe/H]) $= (0.25, -2.26)$ to $(0.46, 0.58)$ varies by less than 50%. Also, metal-rich compositions produce the IBHB stars for only a small range in mass (DRO93, D'Cruz *et al.* 1996), which is the primary cause for the 'first parameter'

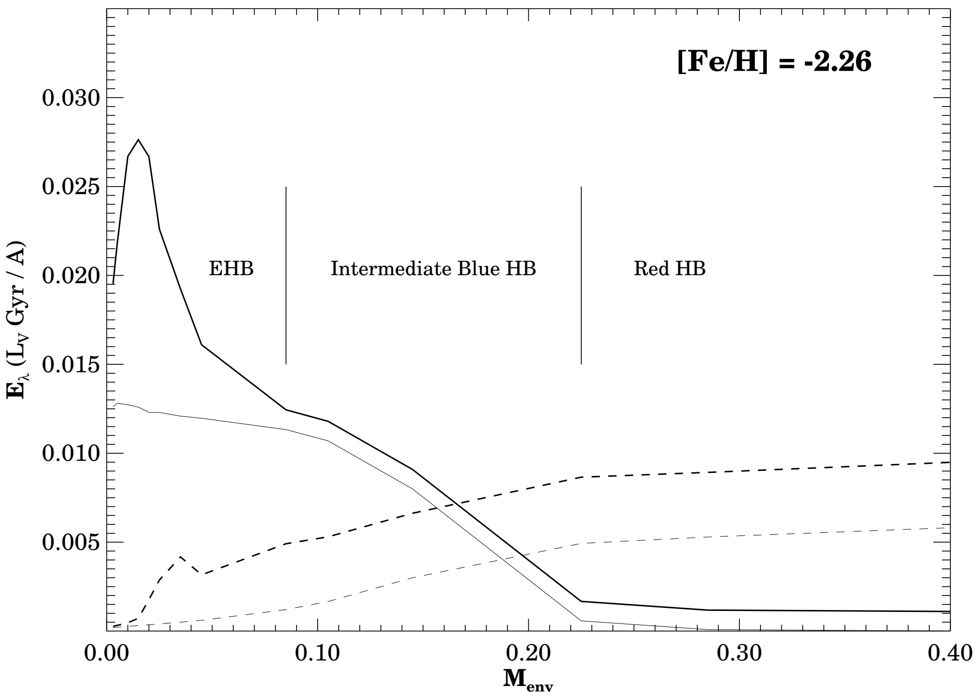

FIGURE 1. The total energy radiated (E_λ) by HB stars at 1500 Å, and in the V band as a function of envelope mass for [Fe/H] = -2.26. The vertical axis is in units of the solar V band luminosity/Gyr/Å. The data has been derived by integrating the DRO93 HB evolutionary tracks and using the Kurucz 1991 model stellar fluxes. For the more massive stars, the 1500 Å flux is radiated entirely in the P-AGB phase of evolution, and the flux from the lowest mass Schönberner (1983) evolutionary track has been adopted (this gives an upper bound to the P-AGB flux; see DRO93).

effect in globular clusters. This also means that far-UV radiation from purely metal-rich populations (above what can be produced by P-AGB stars) requires mass loss in RGB stars to be sufficiently vigorous to strip (almost) the entire envelope.

The other factor that influences the UV production from a stellar population is the rate of evolution $\dot{n}_0(t)$ which is primarily a function of Y, being roughly double the rate at $Y_{\rm ZAMS} = 0.45$ as it is at $Y_{\rm ZAMS} = 0.27$. This reflects the faster evolution of helium rich models.

4.3. *Simple Models of UV Populations*

Equation 4.1 can be simplified to obtain some important bounds on the UV-radiating population. Here, we focus on the number of hot stars that must be present for consistency with the observed far-UV radiation. We assume a simple mass distribution, initial mass function and metallicity distribution as follows. The model consists of:

- an instantaneous starburst at a single metallicity $\Psi = \psi(M)$
- a bimodal HB mass distribution with some fraction f_H of the stars becoming hot.

With the first assumption, our conclusions will of course not give precise metallicity and age information but will instead give luminosity-weighted mean quantities. This

problem is more relevant to the study of radiation in the mid-UV (Worthey, Dorman & Jones 1996).

The HB mass distribution used is justified as follows: the red HB stars of metal-rich populations enter the integrated light mainly in the V-band where their total energy output varies little with envelope mass (this result can also be seen in the metal poor models of Fig. 1, and explicitly in DOR95). The fraction f_H making up the EHB UV emitters realistically is spread over a finite mass distribution (i.e. $f_H = \int_{\rm EHB} P(m')dm'$). This mass distribution cannot be easily distentangled from integrated light, although Brown *et al.* (1997) find that a small mass range of EHB stars produces the best models for the HUT far-UV spectra. In order to avoid adding parameters to the problem that cannot be constrained DOR95 used either single evolutionary sequences and uniform distributions of EHB stars to model the hot contribution. The 'single evolutionary sequence' models can provide an lower bound to the size of the hot population present, since a realistic distribution always produces a redder colour than the hottest stars present. Thus we may choose the peak of the $E_\lambda(M)$ function to derive a bound.

Magnitudes and UV/Optical colours may now be derived from Equation 4.1. The result is

$$m_\lambda - V = -2.5\log_{10}\left(\frac{(\mathcal{L}_\lambda/\mathcal{L}_V)^E + \dot{n}_0(t)\Delta V_0[f_H\mathcal{E}_\lambda^H + (1-f_H)\mathcal{E}_\lambda^C]}{1+\dot{n}_0(t)\Delta V_0[f_H\mathcal{E}_V^H + (1-f_H)\mathcal{E}_V^C]}\right). \tag{4.4}$$

where

$$\mathcal{E}_\lambda^H = \int_{\text{EHB masses}} E_\lambda P(m')dm', \tag{4.5}$$

and similarly $\mathcal{E}_\lambda^C$ is the energy output integrated over the red HB stars. Thus for any given observed $F_{UV} = 10^{[-0.4(15-V)]}$, we obtain (since $\mathcal{L}_{1500}^E \approx 0$)

$$f_H = \frac{F_{UV}(1+\dot{n}_0(t)\Delta V_0\mathcal{E}_V^C) - \dot{n}_0(t)\Delta V_0\mathcal{E}_{1500}^C}{\dot{n}_0(t)\Delta V_0\left[\mathcal{E}_{1500}^H - \mathcal{E}_{1500}^C + F_{UV}(\mathcal{E}_V^C - \mathcal{E}_V^H)\right]} \tag{4.6}$$

For the entire galaxy population, which is composite in abundance, we need to use in this formula the average specific evolutionary flux $\overline{\dot{n}_0(t)}$. A simple but accurate approximation is

$$f_H = \frac{F_{UV}}{\overline{\dot{n}_0(t)}\Delta V_0\left[\mathcal{E}_{1500}^H - \mathcal{E}_{1500}^C + F_{UV}(\mathcal{E}_V^C - \mathcal{E}_V^H)\right]} \tag{4.7}$$

For the specific case where the mass function is taken to be the Salpeter law, $\psi(M) = M^{-2.35}$, DOR95 have tabulated the quantities $(\mathcal{L}_\lambda/\mathcal{L}_V)^E$ and $\dot{n}_0(t)$, and also the values of E_{1500} and E_V for tracks computed by DRO93. Apart from the constant ΔV_0, the terms in the denominator of equation (4.7) are the mean input rate to the HB and the (mean) lifetime energy radiated by the hot stars.

5. Discussion

We have focussed here on deriving limits on the population size responsible for the UV upturn. This is an important prediction of the theory, since is is the most easily tested for consistency against other observational consequences. In particular, for the case of NGC 1399 [$(15-V) = 2.05$] we obtain $f_H \sim 0.16$. This conclusion implies that the UVX

sources do not arise from a trace population more prevalent in UVX-strong galaxies, and instead favours the notion that a sizeable minority of the dominant population is contributing to the UVX.

The work of Park & Lee (1997) and Bressan, Chiosi, & Fagotto (1994) have assumed that a fraction of stars at the low and high end of the metallicity distribution contributes the UV radiation from the galaxies. In the case of the metal-poor hypothesis, a 16% fraction of the population in stars with [Fe/H] < -1 would give a large enough contribution to the mid-ultraviolet radiation to produce a discrepancy with observation (Worthey, Dorman, & Jones 1996; Bressan *et al.* 1994). Quantitative estimates employing the 2500 Å fluxes in DOR95 in equation (4.7) show that bimodal metallicity distributions, in which the majority population contributes relatively little in the mid-ultraviolet, are necessary to reconcile that longer wavelength flux with observations.

The hypothesis that the UVX stars are entirely metal-rich clearly does not suffer from this problem. However, the large fraction of stars necessary to account for the observed flux seems to imply that a spread in metallicity must give rise to the UVX rather than the most extreme composition. This is contrary to the work of Bressan *et al.* who suggest that the UVX arises from the effects of stellar evolution at large ages. They invoke high metallicity, strongly helium enhanced models with RGB mass loss similar to what is inferred from the globular cluster system.

Assuming that it is a fraction of the dominant population that gives rise to the UVX accords better with the observational record we have for Galactic populations. We do not need to hypothesise that *all* RGB stars of a given metallicity have the same degree of mass loss, which we do not observe in any other context (little information about mass distributions can be deduced from red HB clumps). Unfortunately one cannot test the initial metallicity of the field sdB stars easily since their spectra are affected by diffusion in the surface layers. However, the question of how the UVX arises remains open, at least for the time being (but see Dorman 1997a for empirical uses of the far-UV radiation).

It should be stressed that both 'metal-poor' and 'metal-rich' models as presented by these authors rely on the hypothesis that age is established as a 'global' second parameter for HB morphology in old stellar systems. They use the results of simple, unimodal synthetic HB models to derive ages of galaxies. We argue that the Galactic record in resolved populations does not support the use of these models and cannot therefore constrain unresolved stellar populations.

We close with a caveat that applies to the interpretation of the UVX as a metallicity-driven phenomenon, on which the 'metal-rich' hypothesis relies heavily. We caution that this assumption should not be regarded as incontrovertible. The argument for a metallicity driven mechanism is weakened by the discovery that the Mg_2 indicator does not trace the heavy-element abundance in galaxies and by the observation that Mg_2 line strengths are correlated with σ_0 but not with iron indicators (Worthey, Faber, & Gonzalez 1992). The UVX may thus be uncorrelated with iron abundance (Dorman 1997a and references therein). Another definite prediction of the metallicity relation is that the UVX gradient with galactocentric radius should be correlated with optical line-index gradients. This question is currently under study using Ultraviolet Imaging Telescope data (Ohl *et al.*, in preparation). Thus, the Ultraviolet Upturn Phenomenon remains, like many others in astronomy, an unsolved problem which requires spatially resolved spaceborne observations for further study.

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